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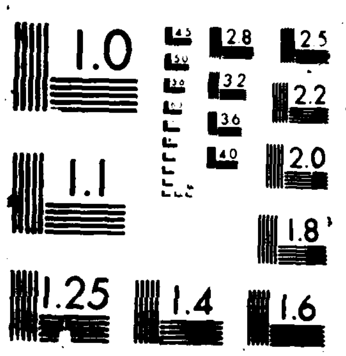
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AF INSTITUTE OF TECHNOLOGY

AN ANALYSIS OF MILITARY FAMILY HOUSING ENERGY CONSUMPTION

THESIS

William L. Jones
Captain, USAF

AFIT/GEM/DEM/87S-12

DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Technical Management

William L. Jones, B.S.
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William L. Jones

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Abstract

This study had two objectives: to determine whether energy consumption was comparable between MFH and non-MFH residencies and to determine the feasibility of appreciably decreasing MFH energy consumption. These objectives were accomplished by examining existing research and literature.

The study found energy consumption tended to be greater in MFH. However, most of this difference is probably due to factors beyond the occupants' control such as house size, house construction, and equipment efficiency. Energy consumption in MFH and non-MFH residencies tended to be comparable under near equal conditions.

Decreasing MFH energy consumption involves increasing the housing units' efficiency and decreasing the occupants' energy consumption. Increasing MFH energy efficiency can be accomplished by using more efficient equipment and appliances and using proper construction materials and techniques to reduce heat loss, heat gain, and number of air changes. These efforts result in a net energy and monetary savings as well as increased occupant comfort.

Decreasing MFH occupants' energy consumption can be enhanced by providing energy education and feedback. These conservation programs produce significant energy savings for a low cost resulting in net energy and monetary savings.

Programs relying on making the occupants financially responsible for the energy consumed are expensive. The major expense is the cost of installing meters in existing houses to enable monthly readings. While these programs do produce some energy savings, present energy costs are low enough to result in a net monetary loss.

Maintenance, repair, and construction of existing and new MFH should be enhanced to increase MFH energy efficiency. Programs should concentrate on providing MFH occupants energy education and feedback. Programs requiring meters should not be pursued. However, meters should be installed on new MFH during construction (when it can be done inexpensively) for possible future use as energy costs rise.

AN ANALYSIS OF MILITARY FAMILY HOUSING ENERGY CONSUMPTION

I. Introduction

General Issue

Energy use resurfaced as an important issue in 1973 because of the Arab oil embargo. This embargo raised the cost of energy and emphasized our nation's dependency on other nations for energy resources. This event along with other subsequent events has kept and will continue to keep energy as an important, national issue. Consequently, energy conservation is being pursued in all areas.

One particular area of interest is energy consumption and conservation in MFH (military family housing). Presently, quarters and utilities (energy) are provided to MFH occupants in exchange for the forfeiture of their BAQ (basic allowance for quarters). There is some disagreement whether these occupants consume more energy than residents of non-MFH. Various proposals have called for action to decrease energy consumption in MFH. Before any actions are taken, the question must be resolved whether there is energy waste in MFH. The answer to this question will be the basis for determining the potential savings to be gained from any energy conservation programs.

If there is excessive energy consumption in MFH, it should be eliminated for two reasons. First, the government should not pay for wasted resources of any kind. Second, all energy waste should be eliminated to decrease our national dependency on foreign energy resources. If MFH energy consumption is comparable to non-MFH energy consumption, a reduction would still decrease government costs and national dependency on foreign energy resources.

Research Objectives

(1) Is MFH energy consumption comparable with energy consumption in non-MFH residencies?

(2) Can MFH energy consumption be appreciably decreased?

Scope

This research examines past studies and research to resolve the two objectives. There is no attempt to introduce any new data by replicating any of these studies.

First Objective. In order to determine whether MFH energy consumption is comparable to energy consumption in non-MFH residencies, several existing studies are analyzed. These studies were accomplished at different times and in various locations. Their methodologies ranged from a straight comparison of energy consumption between houses to controlling most of the pertinent variables affecting energy consumption such as weather, house and family size, and house construction.

Second Objective. In order to determine whether MFH energy consumption can be appreciably decreased, existing studies covering three areas are examined. These areas are behavioral patterns, existing energy conservation programs, and future energy trends.

First, a behavioral approach investigates the reasons affecting people's behavior toward conserving or wasting energy. These reasons can range from a person's income level to their perception of the country's or world's energy situation.

Next, various methods of promoting energy conservation are examined for their effectiveness. These methods range from educating the housing occupants on ways to conserve energy to having the occupants pay a penalty for energy consumption in excess of a predetermined baseline.

Finally, future trends of energy types, costs, and availability are analyzed to forecast the future trend in MFH energy use. With this information, decisions can be made for optimal energy policies.

Limitations. This study does not discuss in any detail the possible impact of areas not directly related to the energy arena due to policy changes. These areas include morale of MFH occupants, Civil Engineering's maintenance responsibilities toward MFH, and unique problems related to some overseas MFH.

Background

It is necessary to know the background of energy use in order to understand our present and future energy use. A knowledge of past energy shortages will help provide an understanding of some potential causes, problems, and results that may be beneficial in helping to cope with present and future energy shortages.

Past Energy Shortages. Energy (fuel) shortages and their consequences are not a new phenomenon as pointed out by Michail Cusack (5:8-9). Much of Western Europe was faced with a wood shortage in the sixteenth and seventeenth centuries. The forests started disappearing as the timber was cut to build houses, ships, furniture, and tools; provide fuel for heating and cooking; and provide charcoal fuel for the steel and pottery industries. Governments passed laws, such as prohibiting the cutting of trees for charcoal, to alleviate the increasing wood shortage. The demand and, consequently, the price of charcoal rose enough to tempt people to break these laws even at the risk of being hanged if caught. The wood shortage developed into a severe energy crisis. Industries were forced to close due to fuel shortages. In homes, only the rich could afford log fires while everyone else had to burn leaves, straw, peat, and low grade surface coal which resulted in less than desirable, smoky, foul smelling fires.

This energy crisis started to subside with the discovery of the vast American forests and the development of techniques to extract higher grade coal from the ground. This higher grade coal became the primary energy source leaving more wood available for uses such as building houses and ships for which there was no substitute material available. The decreased demand for wood allowed the forests, a renewable resource, to eventually replenish themselves.

The nineteenth century saw a different type of energy shortage. At the time, whale oil was the best lamp fuel available. It was also used as a lubricant and as a soap ingredient. As with the wood shortage, the demand for whale oil began to increase thereby decreasing the supply which increased its cost. The substitutes for lamp fuels were distilled from coal and wood but were not popular due to their expense and explosive nature. An acceptable alternative, kerosene, became available when the first petroleum well was drilled in 1859. Kerosene was a better and more abundant lamp fuel than whale oil. Thus, the whale oil demand decreased allowing it to be used for other uses for which there were no adequate substitutes. Also, the whale population, a renewable resource, was able to replenish itself.

Parallels can be drawn from both of these past energy shortages with the present energy situation. Then, as now, the resource's demand and price increased as the supply decreased. No alternatives were available until the shortages were severe enough to be considered a crisis. Again, the energy shortages are amounting to a crisis as demonstrated in 1973 and 1978. Today, alternatives are being pursued, but, so far, none are adequately available.

There are two major differences which make today's energy situation more severe than past shortages. First, today's primary energy resources are nonrenewable. Therefore, as we develop new resources, our existing resources will not be able to replenish themselves. Second, our dependency on other nations for much of these energy resources makes this a political issue. In fact, our national and economic security revolves around this issue.

There is an irony to the comparison of past and present energy shortages. The past shortages of renewable resources were alleviated due to the development of nonrenewable resources. The present shortages of nonrenewable resources will require the development of renewable resources to alleviate the shortages.

America's Energy Before the Shortage. There was an overabundance of energy (wood) in America while the country was starting to grow. The energy need was mainly for domestic purposes in this agricultural country. The arrival of the industrial revolution changed the country's energy requirements. Not only was there an increase in the amount of energy required, but there was also a need for a more efficient fuel (coal) to provide power in this new era. The twentieth century saw oil use increase in the industrial complex. Originally, the U.S. could use its own coal, oil, and gas reserves to fuel its economic growth. By 1947, the U.S. became a net importer of oil the country's largest energy resource (13:445).

<u>Energy Crises Begin</u>. The Organization of Petroleum Exporting Countries (OPEC) was founded in 1960 by Iraq, Kuwait, and Saudi Arabia. Other countries joined OPEC over the next several years. At this time, the Cartel had little control over the worldwide oil market due to oil's abundance and the many sources of oil outside the OPEC countries' borders. U.S. oil and gas production peaked in the early 1970s. America's production of its main energy resource then started to decline, but the demand continued to grow. By 1973, when OPEC was producing half of the world's oil, the U.S. depended on imported oil for 35 percent of its consumption. Half of the imported oil was supplied by OPEC (13:445).

Two events in 1973 greatly affected and changed the supply, use, and outlook for energy. First, Quadaffi seized all foreign-owned oil companies (predominately U.S.) in Libya. The second event, the Yom Kippur War, was more severe in its consequences. The Arab countries cut off oil shipments to the U.S. and other western countries in retaliation for their support given to Israel in the war. The result of this decreased oil supply led to energy shortages which affected the whole economy in the form of gas lines, lost production, decreased utilities, etc.

These two events did not trigger the energy crisis by themselves. The vulnerability due to the dependency on imported oil had been foreseen. "In the three years before the 1973-74 energy crisis, [the U.S. oil industry] began warning of impending shortages . . . but no one wanted to hear about it" (18:16).

The oil embargo was soon lifted. The oil supply quickly rose, but the cost of oil rose even faster. "The sharp increase in the price of oil led to increases in the prices of all goods and services. . . . As a result, the industrial nations experienced rapid inflation and recession" (15:17). New sources of oil were pursued. There was an increased usage of other energy sources such as coal and natural gas. The development of renewable energy sources such as solar and wind power was pursued. People began to think of energy as a limited commodity and started using it that way. Energy ratings on houses, appliances, and cars became important selling points. Highway speed limits dropped to 55 mph. The country was working together to achieve energy independence. This national campaign soon lost its momentum.

People came to accept higher energy costs as long as it was available. Energy conservation efforts and the development of new energy sources lost their impetus. The severe winter of 1976-77 increased the U.S. energy consumption. As the demand exceeded the supply, shortages and higher cost reappeared. This energy crisis was not as severe as the 1973 crisis, but it rekindled the conservation efforts as well as the search for other energy sources. Again, these efforts led to a decrease in the energy demand resulting in another temporary oil glut with corresponding lower prices. As before, the energy independence movement soon lost its momentum.

This has been an ongoing cycle since the 1973 energy crisis. Some event occurs to either cut the supply or raise the cost of oil. These events range from war to agreements by oil producing countries to cut production in order to force the price up. The U.S., like the rest of the industrial nations, then "tightens up its belt." Conservation is reemphasized, and the search for new energy sources increases. This results in a decrease in energy demand which either lowers the price or eliminates the shortage for awhile until the cycle starts over. The cycles should worsen as the nonrenewable resources continue to be depleted.

Since before the 1973 energy crisis, the U.S. has been vulnerable to energy shortages. Each year, the overall reserves of nonrenewable resources decreases by the amount consumed. Additionally, as the reliability on imported energy increases, so does the vulnerability from sources outside of the U.S.

Oil has been emphasized in the modern day energy crises for various reasons. First, oil is the primary energy source in the U.S. Next, the supply and cost of oil is more readily and greatly affected by various factors making it less dependable. Also, it appears oil reserves will be depleted before coal and gas. Finally, oil is used in a wider variety of energy conversion processes and is being used in many products. Thus, oil has a greater impact on our lives.

Other events have had effects on other energy sources. Problems with pollution and acid rain have led to tighter controls on the use of coal for energy possibly reducing greater use of this more abundant but still nonrenewable resource. Nuclear power is being cautiously constrained due to the well publicized accidents at Three Mile Island and Chernobyl as well as other safety and certification problems at other plants. The outlook for these and other energy sources is discussed in Chapter 4.

MFH Energy Use. In 1977, the General Accounting Office (GAO) reported to the 95th Congress that MFH occupants were consuming 30 to 50 percent more energy than similar non-MFH residents. Congress then enacted Public Law 95-82 which directed the Secretary of Defense to accomplish the installation of energy meters on all MFH units, to establish a consumption ceiling, and to assess charges to the occupants on energy consumption in excess of the set ceiling. This program's feasibility was to be investigated before its implementation. The feasibility study is discussed in Chapter 4.

II. Methodology

There are two main objectives to this research effort. The first objective is to determine whether MFH energy consumption is comparable with energy consumption in non-MFH residencies. The second objective is to determine whether MFH energy consumption can be appreciably decreased.

First Objective

To resolve the first objective, this research effort analyzes several existing studies. Limited time and resources prevented performing a full comparison between MFH and comparable non-MFH residencies. Previous studies had already made such comparisons. This research examines a few of these studies. The studies were selected based on their differing locations of observation, times of observations, and methodologies.

The various locations of the studies provided various climates. This allowed differing results based on different weather influences from different types and extremes of weather. Thus, the results are not confined to a particular location.

The studies were conducted at various times allowing comparisons during periods of low and high energy availability and costs. One study took place before the 1973 energy crisis when energy was not a major concern to the consumer. Another study took place before, during, and after the 1973 energy crisis allowing for an examination of any energy consumption differences between MFH and non-MFH residents when facing an energy crisis. Most of the remaining studies took place after the 1973 energy crisis.

The different methodologies used in these studies are mainly dependent on the number of controlled variables. This enables a determination of some of the areas or reasons for any possible differences in energy consumption between MFH and non-MFH residencies.

One particular study is examined in detail. This study compared actual energy consumption of MFH and non-MFH residencies. These residencies were located in the same area and were compared at the same time which eliminated any climatic or geographical variances. Other influential factors such as house construction, house size, and number of occupants were controlled by developing norms with computer programs. Comparing the energy consumption between these MFH and non-MFH residencies gives the amount of excessive MFH energy consumption due to the occupants themselves and not factors beyond their control such as house construction.

Analyzing these different studies' conclusions will determine whether energy consumption is comparable between MFH and non-MFH residencies. Combining the various locations and times of the studies will enable a conclusion to be drawn about MFH energy consumption as a whole and not just for one particular location or time. Combining the various methodologies will help determine any reasons for differences in energy consumption.

Other studies are briefly examined that compare energy consumption between non-MFH residencies having utilities included in their rent with non-MFH residencies where the occupants pay for the actual amount of energy consumed. These studies should generally not be used to make inferences about energy consumption in MFH because of the differences between MFH and non-MFH residencies.

Second Objective

Determining the feasibility of decreasing MFH energy consumption is accomplished by examining individual behavior, previously incorporated energy conservation programs, and future energy trends.

Behavioral Approach. A literature review is used to examine why people conserve or waste energy. Various articles and studies are analyzed to derive a relationship between energy behavior and energy attitudes, energy costs, social norms, and other factors.

Energy Conservation Programs. This section examines several energy conservation programs that have already been implemented or investigated. The programs' advantages and disadvantages are discussed. Also, program costs are compared against the expected savings.

The first of these programs stresses educating the occupants about the need for conservation as well as educating the occupants on ways to conserve energy. The importance of feedback to the occupants is also examined in this section.

The next program examines having the occupants pay for energy consumed in excess of a set baseline. This baseline is determined from the norms discussed earlier. Also discussed are variations of this program such as rewarding occupants for using less than a set amount of energy or giving occupants an allowance and having them pay for their own energy.

The final program concentrates on the MFH units themselves. This section examines incorporating efficient energy conserving materials and techniques into MFH renovation and new construction as the basis for decreasing energy consumption.

Future Energy Trends. The last section examines the outlook (types, availability, and cost) for energy in the future. This is important because of the serious consequences that could result from changes in future energy trends. Waiting until a future energy crisis occurs and then reacting could result in policies being developed in a crisis atmosphere which could be less than desirable. There is a delay between implementing energy policies and obtaining the desired results. This delay results in missed potential savings. Using these future energy trends to develop MFH energy policies helps ensure a continued reduction of energy waste.

Combined Information. Combining the information about individual energy consumption behavior, previously incorporated energy conservation programs, and future energy trends allows for the determination as to whether MFH energy consumption can be decreased.

Different energy programs are examined in context with people's behavior. This shows what programs are most effective at using the methods having the greatest influence over controlling someone's energy consumption habits. This identifies the areas that should be concentrated on for achieving a decrease in MFH energy consumption.

Energy cost and availability are two of the factors influencing energy consumption. Since these factors are subject to large changes, future energy trends are examined to see the effectiveness of different energy conservation programs in the future as the energy arena changes. This allows for recommendations for decisions to most effectively decrease MFH energy consumption.

III. Energy Consumption Comparisons

Many studies have compared MFH energy consumption with energy consumption in non-MFH residencies. The results of these studies have yielded a variety of conclusions along a continuum ranging from no difference in energy consumption to MFH occupants' energy consumption greatly exceeds that of non-MFH residencies.

1965 to 1966 Study

A study by Brandt, Zinder, and Associates (23:4.6) compared the gas usage in MFH with public housing from 1965 to 1966. The gas was used for cooking and heating water. In this unique situation, MFH residents were billed directly for their gas consumption while the public housings' utilities were included in the rent. This study showed MFH residents consumed 8 percent more gas than the public housing residents. The reason for higher consumption of military families was "attributed to the higher income and standard of living, more children, and higher saturation of automatic washing machines" (23:4.6). These results tend to contradict the many studies stressing the almost absolute dependence of energy consumption with the cost of the energy. In this study, the families using the least amount of energy were the ones incurring the least "additional" cost. This usage versus cost relationship will be discussed in greater detail in the next chapter.

1973 Study

A study by Booz, Allen, and Hamilton (23:4.6) in 1973 compared the electrical consumption between MFH at Pensacola NAS, Florida and local civilian residencies. Their conclusion was "electricity consumption levels for naval housing appear to be substantially higher than those for comparable civilian housing" (23:4.6). Some of the variables not accounted for in this study include family size, house size, house construction, and equipment and appliance efficiency. This makes it impossible to determine whether the additional electricity consumption is due to larger houses or families (which must be considered to give equal per person comparisons), excessive use by the occupants, or inefficient houses which are not the responsibility of the occupants.

1970 to 1976 Study

Bjerke and Brown (23:4.7) in a 1976 thesis at the Air Force Institute of Technology compared electrical consumption between MFH and civilian residencies from 1970 to 1976. Fifty-eight Air Force, Navy, and Marine Corps housing sites were looked at while acceptable data was available for only four local civilian housing areas. They concluded the following:

> over a 5- or 6-year horizon since 1970, consumption of electrical energy in military housing at those four installations has exceeded consumption in comparable civilian housing by approximately 23 percent [23:4.7].

Acceptable consumption data was available for eight additional local civilian housing areas for 1975 only. This comparison showed 1975 MFH energy consumption "exceeded consumption by comparable civilian housing by approximately 17 percent" (23:4.7). Bjerke and Brown further concluded the difference between military and civilian electrical energy consumption is diminishing. As in the previous study (Booz, Allen, and Hamilton), there is insufficient information available to infer any reasons for greater electrical consumption in MFH.

Note that the "diminishing consumption differences" continued during and after the 1973 energy crisis. This could have been due to several reasons. First, the MFH occupants, being a part of the military, may have been more sensitive to the political significance of the crisis, thus conserving more even without monetary gain. A survey of Navy MFH occupants was conducted in 1978 during an energy crisis which was less severe than the 1973 crisis. The majority of the occupants had the following thoughts:

> the mid-1978 energy situation was sufficiently serious to call for changes in behavior . . . and [they] endorsed changes in [the] U.S. way of life, such as resetting thermostats and reducing personal comfort to save energy [23:4.1].

There could also have been an increase in the efficiency of MFH and related equipment and appliances. Another possible reason for the decrease is that prior to 1973, energy was considered to be a low to no cost item hardly worth considering as a benefit. Since the 1973 energy crisis and the subsequent increase in energy costs, MFH occupants see energy as a benefit not to be abused for reasons of costs to the government and national interest.

<u>1978 to 1979 Study</u>

Another comparison of energy consumption between MFH and local civilian residences was conducted in 1978 and 1979 at the Naval Weapons Station, Charleston, South Carolina (23:4.8). Houses of fairly comparable construction and size were selected. There was no information available on the occupants or the equipment and appliances in the houses. Energy consumption in MFH averaged 7.95 percent more than civilian residencies over the 21 month period.

> However, other research has shown that the average Navy family is larger and has more electric appliances than residents in comparable civilian housing. Therefore, it appears that the average Navy Family's consumption of energy is very similar to the civilian counterpart [23:4.8].

This study more effectively compares energy consumption in military and civilian houses than the previous studies. However, there are still many uncontrolled variables that must be addressed in order to give a more accurate comparison.

<u>Other Studies</u>

There have been many other studies among civilian residencies such as Midwest Research Institute; San Diego Gas and Electric Co; and Booz, Allen, and Hamilton. These studies concentrate on comparing energy consumption between residents that pay directly for the energy they consume with residents who have their energy costs included in their rent. The results range from no difference to up to 35 percent (20 percent being the approximate norm) greater usage among residencies having energy costs included in the rent (23:4.7-4.19). Natural gas consumption tends to reflect only a small difference. Each of these studies have inherent problems in comparing the two housing groups such as comparisons at different times and locations resulting in climatic and geographical differences. There are also many of the uncontrolled variables mentioned in the previous studies. This results in suspect findings. Again, the reasons for the differences cannot be determined from the information.

Most of these studies give the main reason for the increased consumption as being financial, i.e. the residents tend to use more energy if they do not pay directly for it. Another reason relates to the lack of feedback the residents receive as to how much energy they are using. These reasons will be discussed in greater detail in the next chapter.

There can be various reasons for differences in energy consumption between MFH residents and civilian residents who have their energy costs included in their rent. First, MFH may have thermostats with minimum and maximum settings which prevents abuses of the heating and cooling systems. The use of these thermostats and their minimum and maximum settings is dependent on base policy. Also, there are "no heat" and "no cool" seasons where the heating and cooling systems are not operational. This period is dependent on climate and base policy. Next, there are many programs to educate the occupants about the ways and the need to conserve energy. Also, MFH occupants probably realize the energy supplied to them is a benefit that cannot be abused. Being in the military, they may be more attuned to the importance of conservation. Finally, some of them may have been exposed to and adopted more conserving life-styles while living overseas.

Because of these possible consumption differences, comparisons between civilian residents paying directly for their energy and civilian residents with utilities included in their rent should undergo careful scrutiny before being used as an estimation of MFH residents' energy consumption trends. This is reinforced by the tendency for comparisons between two groups of civilian houses to show a greater difference in energy consumption than the difference reflected between MFH and civilian houses.

Port Hueneme Study

A comparison of energy consumption was performed in 1979 between MFH at the Navy Construction Battalion Center at Port Hueneme, California, and local non-MFH residencies in Oxnard, California (22:6.1-6.56). MFH occupants did not pay directly for their utilities while the non-MFH occupants did. Since these houses were located in the same area, there were no discrepancies resulting from differing climates. See Table I for the differing variables between MFH and non-MFH units.

The study included 20 MFH duplex residencies averaging 1,239 square feet and 26 non-MFH single and multifamily residencies averaging 1,065 square feet. The average occupancy rate was 4.4 occupants per MFH unit and 3.9 occupants per non-MFH residence. This equates to a similar square footage per occupant for both sets of houses. The civilian houses were built around 1975, and the MFH units were built between 1962 and 1965. The construction was fairly similar for all the units. The MFH occupants consisted of adults primarily 31 to 40 years of age with their children averaging 10 years. The non-MFH residencies consisted of adults primarily in the 18 to 30 year age bracket with their children averaging 6 years. All heating and water heaters were natural gas with the capacity being a little greater in MFH.

All units had natural gas ranges with about one third of the MFH units having microwaves versus none for the non-MFH residencies. This could have resulted in a higher use of electricity and a lower use of natural gas in MFH. All non-MFH residencies had a dishwasher versus about one third of the MFH units. This could have resulted in a higher use of electricity and possibly a higher use of natural gas for heating water in the non-MFH residencies. While all of the non-MFH residencies had a refrigerator, only one had a

TABLE I

Housing Variables

	MFH	NON-MFH
Average # Appliances/Unit		
Microwave	.35	0
Dishwasher	.3	1.0
Refrigerator	1.4	1.0
Freezer	.5	.04
Washing Machine	1.0	.65
Dryer (Total)	1.0	.65
Electric	.85	0
Natural Gas	.15	.65
Televisions	1.4	1.0
Average Square Feet/Unit	1239	1065
Average # Occupants/Unit	4.4	3.88

freezer. Half of the MFH units had freezers. They also averaged 1.4 refrigerators per MFH due to several houses containing the occupant's personal refrigerator along with the government refrigerator. Even though the military families tended to be larger and have older children, these extra refrigerators were probably excessive and added an unnecessary amount of electrical consumption. All MFH units had washing machines versus only two-thirds of the non-MFH residencies. All of the MFH units had clothes dryers (predominately electric) while only two thirds of the non-MFH residencies had dryers which were heated with natural gas. This greatly increased the MFH electrical consumption while only moderately increasing the non-MFH residencies' natural gas consumption. Finally, the MFH units averaged 1.4 televisions versus only one for the non-MFH residencies. The energy usage of all appliances was greater in MFH than in the non-MFH residencies.

The actual energy consumption of the houses was measured from mid-January to mid-July. These measurements were grouped into three bimonthly periods which were labeled Late Winter, Spring, and Early Summer (see Table II "Per Unit"). The natural gas and electrical consumption were converted to therms. There was little discrepancy due to differing fuel efficiencies because the houses used the same fuels for similar operations except for some clothes dryers.

The Late Winter period (mid-January to mid-March) resulted in MFH residencies consuming about 32 percent more

TABLE II

Energy Consumption

	Percent of MFH Energy Consumption in Excess of Non-MFH Energy Consumption	
	Per Unit	Per Occupant
Late Winter		
Natural Gas	22%	08%
Electricity	104	81
Combined	32	17
Spring		
Natural Gas	23	09
Electricity	80	63
Combined	33	17
Early Summer		
Natural Gas	11	(-1)
Electricity	87	66
Combined	28	13
6 Month Total		
Natural Gas	13	04
Electricity	91	69
Combined	30	14

energy per unit than the non-MFH residencies. This consisted of 22 percent more natural gas and 104 percent more electricity. The Spring period (mid-March to mid-May) resulted in MFH residencies consuming about 33 percent more energy (23 percent more natural gas and 80 percent more electricity). Finally, the Early Summer period (mid-May to mid-July) resulted in the MFH residencies consuming 28 percent more energy (11 percent more natural gas and 87 percent more electricity). The average for all six months showed the MFH residencies consuming 30 percent more energy (13 percent more natural gas and 91 percent more electricity).

These numbers decrease significantly by controlling the variable of number of occupants (see Table II "Per Occupant"). There were 4.4 occupants per MFH unit while only 3.88 occupants per non-MFH unit. This shows the importance of controlling the variables when comparing energy consumption. The Late Winter period resulted in MFH occupants consuming about 17 percent more energy per person than the civilian residents. This consisted of 8 percent more natural gas and 81 percent more electricity. The Spring period resulted in MFH occupants consuming about 17 percent more energy (9 percent more natural gas and 63 percent more electricity). Finally, the Early Summer period resulted in the MFH occupants consuming 13 percent more energy (1 percent less natural gas and 66 percent more electricity). The average for all six months showed the MFH occupants consuming 14 percent more energy per person (4 percent more natural gas and 69 percent more electricity).

The Port Hueneme study's results are comparable to the other studies' results. The other studies showed a wide range of differences in energy consumption between MFH and non-MFH residencies. While the range varied greatly, the general tendency was for a 15 to 20 percent greater energy consumption in MFH. This study showed a 14 percent greater consumption per occupant in MFH which is comparable with the results of the other studies.

There are still several reasons why this figure may be a little lower than other studies. First, the MFH occupants knew about this study while they may not have known about some of the other studies. This may have decreased their energy consumption during the observation period. Next, the MFH occupants received mock utility bills providing them with feedback as to the amount of energy they were consuming. This feedback was not provided in most of the previous studies. The effects of feedback will be discussed in the next chapter. Also, the weather at this location is relatively mild. A more severe climate could result in a greater difference in energy consumption as residents paying directly for their energy adjust their thermostats to help offset higher energy bills. Finally, several variables were controlled by using houses in the same location, of similar construction, and with a similar composition of occupants. Other studies had less control over some of these variables.

These few variables were controlled in this part of the Port Hueneme study. Controlling the remaining variables was accomplished in the next part of the study.

A method of calculating the normal expected energy consumption (Norm) of individual housing units was developed by Science Applications, Inc. (SAI) for this study. This method was derived from a procedure developed by the Office of the Secretary of Defence (OSD) and the U.S. Army Construction Engineering Research Laboratories (CERL). The Norm is the result of combining factors from the house structure and factors related to how the occupants affect energy consumption.

First, a modification of the Home Energy Audit Program (HEAP) was used to estimate heat loss and gain to the houses. The HEAP was developed by the National Bureau of Standards (NBS). This program was chosen for use from several other programs because of its ease of use, low cost, and flexibility. The effectiveness of the modified HEAP at calculating heat loss and gain was validated against a more detailed Building Loads Analysis and System Thermodynamics (BLAST) program. Both programs were run for a town house in Washington D.C. The results were different for the heating and cooling seasons. The modified HEAP predicted less heating requirements and greater cooling requirements than those predicted by BLAST. This is an important point when looking at using the program for establishing a baseline above which a penalty is incurred by the occupant. However, the point is not important for the purpose of comparing energy consumption between MFH and non-MFH residencies as long as the same program is used on both sets of houses. The variables controlled by the HEAP include wall U-values; wall surface absorbability; shading coefficients for walls, roofs, doors, and windows; building air changes per hour; attic air changes per hour; air leakages through ducts; ground reflectance; and the effects of thermal lag on the facility.

A method for calculating Norm appliance energy consumption was developed to provide a fair estimate of energy consumption needed by the housing occupants. These estimates were based on previous studies relating the amount of energy that would probably be consumed by various appliances given the number of occupants per household and the time of year or climatic conditions. The appliances include ranges, dishwashers, air conditioners, clothes washers and dryers, and water heaters.

Combining the modified HEAP and the appliance energy consumption calculations gives the normal expected energy consumption (Norm). The Norms were calculated for the MFH and non-MFH residencies and were compared against the actual consumption (see Table III). These Norms are the means for controlling most of the remaining, pertinent variables.

The non-MFH residencies consumed 112% of the calculated Norm energy requirements (112% of natural gas and 109% of electricity) during the Late Winter period. During the same

TABLE III

Energy Consumption as Percent of NORM

	Actual Consumption as Percent of NORM			
	Natural Gas	Electricity	Total	% of NON-MFH
NON-MFH				
Late Winter	112	109	112	-
Spring	158	108	147	-
Early Summer	107	99	105	-
Total	141	106	134	-
MFH				
Late Winter	85	164	94	84
Spring	125	148	130	88
Early Summer	118	140	124	118
Total	110	151	117	87

period, the MFH units consumed 94% (85% of natural gas and 164% of electricity) of the calculated Norm for these units. Comparing the actual MFH and non-MFH energy consumption with the respective Norms yields a 16% less usage in MFH.

The non-MFH residencies used 147% of the Norm (158% of natural gas and 108% of electricity) during the Spring period. MFH used 130% of the Norm (125% of natural gas and

148% of electricity) during this period. A comparison shows a 12% less usage in MFH.

The non-MFH residencies used 105% of the Norm (107% of natural gas and 99% of electricity) during the Early Summer period. MFH used 124% of the Norm (118% of natural gas and 140% of electricity) during this period. A comparison shows an 18% greater usage in MFH.

Overall, the non-MFH residencies used 134% of the Norm (141% of natural gas and 106% of electricity). MFH used 117% of the Norm (110% of natural gas and 151% of electricity). An overall comparison shows a 13% less usage in MFH.

The study noted MFH natural gas consumption was lower than non-MFH consumption for heating requirements but higher for cooking and water heating. The electrical consumption, lighting and appliance loads, was also higher in MFH. This shows the MFH occupants using less energy (natural gas) for heating and more energy for all other purposes.

A possible problem with this conclusion, based on this author's experience, is that the MFH occupants may have been supplementing their natural gas heating with portable electric heaters. This would account for the greatest under usage of natural gas and over usage of electricity, as compared against the Norm, occurring in MFH in late winter. If this is the case, then adjusting for this would reflect more closely related consumption levels for heating and for other purposes between MFH and non-MFH residencies.

Summary

This research has looked at several existing studies to determine whether MFH energy consumption is comparable to energy consumption in non-MFH residencies. These studies were conducted between 1965 and 1979.

Some of the studies compared energy consumption between non-MFH residencies where the occupants paid directly for their utilities and non-MFH residencies where the utilities were included in the rent. Even though these later residencies are similar to MFH in regards to the utilities being included in the rent, there are still several differences. These differences result in the energy consumption of the two groups possibly being different. Therefore, these studies between two non-MFH groups should not be used as a comparison with MFH energy consumption.

Some of the studies controlled very few variables while others controlled many variables such as house size, type of construction, and climate. Generally, controlling more variables in a study resulted in a smaller difference of energy consumption between MFH and non-MFH residencies.

The Port Hueneme study controlled almost every pertinent variable and showed the energy consumption in MFH was actually less than non-MFH residencies under near equal conditions. A straight comparison without controlling most of these variables showed a 14 percent greater energy consumption per person and a 30 percent greater energy consumption per unit in MFH. These figures are comparable to the results of the other studies controlling only a few variables. Thus, the Port Hueneme study should be considered to be of typical MFH and non-MFH residencies and should not be looked at as a unique situation.

Is MFH energy consumption comparable with energy consumption in non-MFH residencies? The answer is no for the studies examined in this research. However, this is probably due to circumstances beyond the control of the occupants. Under near equal conditions, Port Hueneme MFH energy consumption was comparable to non-MFH energy consumption. This shows the importance of controlling pertinent variables when comparing different housing groups. As studies compared more variables, the difference in energy consumption between MFH and non-MFH residencies decreased. The Port Hueneme study emphasized this. In this study, 30 percent greater MFH energy consumption with uncontrolled variables equated to 13 percent less consumption under near equal conditions. The housing was typical of other locations; however, the climate was fairly mild possibly resulting in better than typical results for MFH energy consumption.

Determining whether a particular MFH area consumes a comparable amount of energy with non-MFH residencies in the same area would require a study of houses in that area. This study would have to control all pertinent variables to determine if the occupants are consuming a comparable amount of energy under near equal conditions. Existing research tends to show energy consumption to be greater in the particular MFH areas studied. Research also shows the occupants' consumption would probably be comparable if the pertinent variables were controlled making near equal conditions.

As energy costs rose due to the energy crises, these studies showed no increase in energy consumption differences between MFH and non-MFH residencies. This was a period when residents paying directly for their utilities tended to reduce their consumption to offset rising energy costs. Some studies showed that due to energy conservation programs MFH had a greater decrease than non-MFH residencies in energy consumption even though the MFH occupants would not benefit monetarily. "According to available data, between 1975 and 1979 there was an actual 7.7 percent energy consumption reduction in military family housing" (23:7.15). This reinforces the point that overall, MFH residencies are continuing to use an amount of energy comparable to non-MFH residencies.

Just because energy consumption in MFH is comparable to energy consumption in non-MFH under near equal conditions, does not mean that energy consumption cannot be appreciably decreased. The next chapter investigates ways of decreasing energy consumption.

IV. Energy Conservation

This chapter addresses the second objective by investigating the feasibility of decreasing MFH energy consumption. This is accomplished by examining housing occupants' behavior toward energy use, existing energy conservation programs, and energy's future trends.

Behavioral Approach

This section examines existing studies and research to determine why people consume and conserve different amounts of energy. The areas investigated include cost to the occupant, comfort, attitudes, feedback, and information.

A study conducted for the Navy Personnel Research and Development Center (22) includes a survey of Navy MFH occupants which should be viewed cautiously. A survey on energy use would not only tend to have an inferred "socially acceptable" response but could also be suspected, by the surveyees, of resulting in actions being taken against them based on their responses. Both of these situations could lead to inaccurate data due to the respondents trying to appear socially conscious or trying to influence an anticipated action (7:184). This problem of inaccurate data in surveys is "particularly [evident in] the energy conservation field where pressures to appear socially responsible may lead individuals to overstate their conservation behaviors" (2:504).

Cost. The predominate reason for wasted or excessive energy consumption in MFH is assumed to be because utilities are included with the quarters. If this is true, holding MFH occupants financially responsible for the utilities may reduce MFH energy consumption. Thus, cost would be the impetus for energy consumption. "The cost based model argues that increased prices [or cost to the occupant] lead to decreased consumption" (2:555). Research has shown the following:

> Among renters, particularly those who reside in multifamily dwellings where utility bills are either partly or wholly included in the rent, . . . separate meters, and hence, separate electricity bills [would be required] in order to reduce energy consumption [10:349].

The survey results of Navy MFH occupants contradict this statement. A large number of respondents felt people who pay for their own utilities do not necessarily use less energy. These MFH occupants considered themselves to be conservers. Most of them said they would put conservation before personal comfort. This tendency of conservation before comfort was stronger in milder climates than areas with harsh winters (22:v). As stated previously, these survey results may contain biased responses.

Most research has shown a different effect of cost on different income levels. Some studies found energy costs had little effect on energy consumption in higher income households. However, these studies found "price was the major influence that induced energy conservation in lower and middle income households" (2:557). Other studies contend "the rich are more willing, more able, and actually conserve more energy than the poor" (10:340). This was because the rich could more readily invest in energy conservation devices and home improvements.

After examining existing research, the Navy noted varying energy consumption among lower, middle, and higher income brackets. The lower income groups consume the least energy even though they engage in few conservation practices. The middle income groups save the most energy. The higher income groups offset their energy savings from more efficient houses, equipment, and appliances with higher consumption. The Navy's survey showed energy usage was related more to the MFH occupants' perception of their economic level than their actual income level. The MFH occupants who felt they could least afford any extra expenses reported more conservation behavior even though they did not pay for their utilities (22:22).

Of the studies stressing cost to the occupant as the main factor affecting energy consumption, there was a difference of opinion as to how residents of different income levels were affected. The difference seemed to revolve around the cost and benefits of energy conservation methods that may or may not be pursued by the occupants. "As expected, homeownership increases the likelihood of adopting conservation methods" (10:345). With relatively short term rental housing, there is probably little to no investment by the occupant in energy conserving devices. If the occupant is paying for the utilities, then the landlord will have less concern with investing to cut utilities. The government is essentially the landlord of MFH. Similar to the landlords of non-MFH residencies with utilities included in the rent, the government is more attuned to investing in construction, maintenance, repair, and efficient appliances to cut its energy costs. Therefore, energy conserving measures are common throughout MFH without regard to income level of the occupants. This eliminates the problem of higher income residents investing in more energy conserving methods. Most studies agree higher income residents consume more energy in similar houses. This gives merit to the correlation between income level and energy consumption. However, this may be due to reasons such as lower income families being younger families with fewer children thus, consuming less energy. This may explain the results of the Navy study discussed earlier showing lower income MFH occupants consuming less energy even though they did not pay for the utilities.

Comfort. In addition to cost, research has shown comfort as another major factor influencing energy consumption. Some studies concluded "thermal comfort considerations were more important than perceived financial pressures in predicting energy use" (2:556). It is important to note thermal comfort is relative to the individual, and it is the perception of comfort that matters. For example, if a resident perceives turning off the air conditioner and opening windows will make the house uncomfortable, whether it does or does not, then the occupant will leave the air conditioner on.

Many studies have related the importance of comfort versus cost with a resident's income level. These studies look at comfort as a commodity all households desire. However, not all households are able to afford this commodity. Again, because comfort is a relative term, energy consumption may vary based on the occupant's comfort level (2:557).

Most studies appear to classify the effects of comfort on energy consumption into three main criteria: what is the occupant's comfort level, what comfort level can the occupant afford, and what is the relative importance of the comfort level to other matters such as energy conservation versus national security? These criteria may affect MFH residents differently than they affect non-MFH residents.

Individuals have different comfort levels. "Present [energy] consumption sets a threshold of comfort to which one is accustomed" (2:558). Therefore, the occupants of each housing unit generally have about the same comfort level. MFH energy usage has some constraints such as "no heat" and "no cool" seasons and minimum and maximum thermostat settings as discussed in the previous chapter. These constraints may affect some occupants' comfort levels while not affecting others. The constraints help eliminate energy abuses from individuals with relatively extreme comfort levels.

Being able to afford a certain comfort level is not a factor affecting MFH occupants. Thus, lower income residents normally unable to afford their desired comfort level may consume more energy than their counterparts paying for their utilities. Residents with an income high enough to support their comfort level would probably consume about the same amount of energy regardless who pays for it.

MFH residents may be more attuned than most non-MFH residents to the relative importance of energy conservation. MFH occupants receive a lot of information on the need for energy conservation. Being in the military, these residents are probably more aware of the importance of national security and its relationship with energy conservation.

Attitudes. In a study of MFH occupants, the Navy found its "respondents' present conservation behavior can best be predicted by their past conservation behavior; and their future conservation behavior, by their attitudes toward energy conservation" (22:vi). However, other studies of non-MFH residents showed no definite relationship between energy related attitudes and conservation behavior (4:522). The differing results of these two studies may be due to non-MFH residents paying directly for utilities while MFH residents do not. Attitudes are tied in with other factors. In non-MFH, the residents' energy conservation actions may result in monetary savings. However, MFH residents will not gain monetarily from their conservation actions. But there is a threat of loosing the benefit of paid utilities if they abuse the benefit. "Individuals are more likely to take action to avoid or minimize a loss than they are to secure a gain" (4:524).

Research has looked for relationships between energy conservation and belief in the seriousness of the energy situation. Some studies have found "increased conservation efforts were positively associated with increased belief, while [other studies] found no association" (22:1). If there is a relationship, then the residents' perception of the energy situation is very important. During a severe energy crisis, most people recognize the seriousness of the situation. However, some people think these crises are fakes orchestrated by the government or the oil companies. After the crisis, people tend to forget what had been a serious problem. In 1981, energy was identified as a major concern by more than 60 percent of the country. By 1984, only 3 percent of the country identified energy as a major concern. Most Americans also believe alternative sources of energy will be found preventing any future energy crises (3:10).

Martin Kuchler of Michigan's Energy Administration stated: "People may be very positive toward energy conservation. But if there are no events prodding them toward action, people let energy conservation slide"

(3:10). Lawrence Kaagen, vice president of a forecasting and market research firm stated:

> For a sense of urgency to return -- to energy or any other issue -- at least one of three things must happen. First, a grassroots movement could arouse concern. Second, news events could galvanize people into action. Third, energy shortages could hit people where it hurts -- in their pocketbooks [3:10].

His third point of cost affecting energy consumption was discussed earlier. The other two points could be applied to MFH through an energy conservation program. This will be discussed in the next section.

There is one other important attitude affecting some residents. After an energy conservation improvement has been made, the resident realizes the same life-style will result in less energy consumption. Therefore, some residents may raise their comfort levels resulting in little decrease of their original energy consumption prior to the improvement. Thus, some of the program's expected savings will be lost (8:22).

Feedback. Feedback is an important element in energy conservation. Studies have shown energy usage feedback can reduce residential energy consumption (22:3-45).

When residents had to feed a wood stove or coal-fired furnace, they were continuously aware of the amount of energy they were consuming. Now, energy is available at the flip of a switch. The only energy consumption feedback received by residents is a monthly bill. Even this is not present in MFH.

One area of research used three basic methods of providing energy consumption feedback to residents. The first method installed meters to provide digital readouts of daily consumption in dollars and cents. This would probably be effective in lower income residencies where the occupants pay directly for their energy. These residencies are more likely to conserve for monetary reasons. However, these meters could also be useful in MFH by providing energy consumption feedback in an understandable term such as dollars and cents instead of kilowatt hours. The next method provided the occupants with daily or weekly energy consumption readings. This was the same as the first method but helped ensure the occupant would get the information. The final step presented detailed information on the monthly bill. This lessened the feedback frequency (4:526). Use of these methods is discussed in the next section.

Energy usage feedback by itself is important. It can also add to the savings of other energy conservation programs. These other programs are usually measured for their effectiveness. Thus, the information is already available. The pertinent information could easily be passed on to the occupants. This feedback allows the occupants to see the results of different energy conservation programs. Acceptance of these programs' effectiveness is an important part of getting the occupants to comply with the programs

Information. "It appears that many efforts to encourage conservation behaviors fail to communicate the information that is vital to their success" (4:522). This is a major reason many energy conservation programs fail to reach their goals. Even though many residents claim to have an accurate understanding of the information, many do not. One study noted the following:

> The difference between claimed awareness and accurate information is substantial. Although roughly one half to three quarters of all respondents claimed familiarity with the conservation programs, accurate understanding of these programs was rare and, in some cases, negligible [4:522].

Four events must occur before a resident accepts an energy conservation program. The program information must be perceived, accurately understood, favorably evaluated, and remembered. Each of these steps is necessary to influence the residents to accept the program (4:523).

First, the residents must perceive the information. Most information about energy conservation is presented in dull or overly technical formats. The resident fails to develop an initial interest in this information, thus it is not pursued. To be effective, the information must attract and hold the resident's attention.

Second, the residents must accurately understand the information about the program. This applies to information about energy use and conservation as well as any programs being implemented. If residents "are unable to understand the consequences of how they use energy, they are unable to develop effective strategies for reducing energy consumption" (4:526).

Third, the residents must favorably evaluate the information. How the information is presented impacts on how it is evaluated. "Research on human information processing suggests that people tend to assign disproportionate weight to 'vivid' information that is highly concrete and personalized" (4:523). Also, "a message attributed to a highly credible source produces greater attitude change than the same message attributed to a less credible source" (4:524).

Finally, the resident has to remember the information so it can be put to use. Clear, specific, concrete information is remembered best. Vague messages such as "conserve energy" are less effective than specific conservation recommendations. Also, more familiar terms such as dollar's worth of energy are more easily remembered than kilowatt hours (4:525).

There are two main ways of delivering the information to the occupants: mass media advertising and the interpersonal approach. Mass media advertising has been the dominant approach. It is the same process used by firms to promote or sell a product. Research has shown mass media advertising "should not be the sole or even the primary component of an overall influence strategy" (16:526).

Information received from friends and acquaintances may be more influential than information from non-personal media sources. This is because the information may be more vivid and personal and the source may be deemed to be more credible (4:527). The Navy study found "perceptions of what others are willing to do to save energy is not a statistically significant factor affecting what individuals themselves are willing to do" (22:3.47).

Both methods of delivering information are important. Media sources are effective in creating awareness of conservation methods. Interpersonal sources such as friends exert a greater influence on one's decision to adopt these conservation methods (4:528).

Summary. Energy use is affected by cost to the occupant, comfort level, attitudes, feedback, and information available to the occupant.

The cost based model states increased energy cost to an occupant leads to decreased energy consumption. Studies show this may be true among lower income residents but probably not among higher income residents who can afford to maintain their comfort level. Studies also show higher income residents tend to consume more energy than lower income residents. Under this model, higher income MFH occupants would probably not consume much less energy if they paid directly for their utilities. However, lower income MFH occupants might reduce their energy consumption if severe heating or cooling requirements and high energy costs forced their comfort level beyond their financial capabilities.

Studies show the importance of residents' comfort level with energy consumption. The key factor is not whether the residents can afford a certain comfort level, but what is the comfort level. There is still a relationship between comfort level and income level because a higher resident comfort level would require a higher income level. MFH occupants maintain a comfort level without regard to cost. If they paid directly for their own energy, there probably would be some occupants who would use less energy because they could not afford their comfort level. There could also be an increase in MFH energy consumption. If the occupants were to pay for their own energy, there would be no constraints such as "no heat" and "no cool" seasons or minimum and maximum thermostat settings. Occupants with comfort levels beyond the constraints and who could afford it would probably increase their energy consumption to meet their comfort levels.

There is a difference of opinion as to whether attitudes affect energy conservation behavior. If there is a relationship, programs should concentrate on what can be lost (national security, energy independence, etc.) by not conserving energy instead of what can be gained (monetary savings for the government) through energy conservation. There is also a difference of opinion as to whether the perception of the energy situation affects energy conservation behavior. If their is a relationship, then efforts should be increased to inform the occupants of the seriousness of the energy crisis. Also, some occupants may increase their comfort level after implementing an energy conservation program or device which limits the original savings.

Feedback should be given to residents so they will know how much energy they are consuming. This feedback should be presented in an understandable form such as dollars and cents instead of kilowatt hours. Any energy conservation program should incorporate feedback to enable the occupant to see the program's effectiveness.

Information about energy conservation and energy conservation programs must be perceived, accurately understood, favorably evaluated, and remembered. Therefore, the information must be clear, specific, concrete, vivid, in familiar terms, and from a credible source. Information may be delivered through mass media advertising or interpersonal means such as friends and acquaintances. The media sources are more informative while the interpersonal means are more influential.

Energy Conservation Programs

This section examines different energy conservation programs that have been implemented or investigated in MFH or non-MFH residencies. These programs are categorized into one of three groups: education; occupant energy payment; or construction, maintenance, and repair. "Carefully designed and implemented evaluations [of energy conservation programs] can provide valuable information on what works and what does not" (15:428).

Education. Energy education is an important part of reducing energy consumption. Fred L. Hartley, Chairman and Chief Executive Officer of Unocal Corporation stated: "We are going to need all the wisdom and knowledge about energy that we can muster if we are to maintain our economic and political strength in the years ahead" (13:444). This pertains to housing residents as well as policy makers.

1979 Study. A study in 1979 by the Navy Personnel Research and Development Center (19) emphasized the potential savings to be gained by educating MFH residents. Two hundred enlisted MFH units at the Pensacola Naval Air Station, Florida, were equally divided into a control group and a treatment group. Individual weekly meter readings for both housing groups were recorded for 14 weeks (25 July to 31 October). The treatment group was involved in an education program for 8 weeks (from week 2 through week 10).

The education program consisted of several parts. A newsletter was distributed every 2 weeks to each residence in the treatment group. This newsletter contained energy conservation tips, announcements of related events for the treatment group, and energy consumption comparisons of the two groups. Other information was continuously sent to the treatment group including pamphlets about electricity; a conservation cookbook; and a comic book, poster, and stickers for the children, thus, getting the whole family involved. Scheduled events included a poster contest, speakers, and a power plant tour. A program coordinator visited the treatment group households providing personal communication and a sincere interest.

The treatment group consumed up to 4 percent more electricity than the control group during the 2 weeks prior to the education program implementation. By week 3 of the education program, the treatment group was consuming less electricity than the control group. A relatively stable 4 percent consumption reduction was achieved by the treatment group by week 5 of the education program. This level was maintained for the next 4 weeks of the education program and for the remaining 4 weeks of the study after the education program was terminated (19:5).

Some of the treatment group members shared information provided to them with some of the control group members. This may have resulted in decreased electricity consumption in the control group. Also, the higher consumption by the treatment group during the 2 weeks prior to the education program implementation may have shown this group to be larger energy consumers than the control group. Therefore, the education program may have provided a greater than 4 percent savings. Program refinements were expected to yield even greater savings with less effort (19:viii).

Some of the participants were interviewed to get their thoughts about the education program. The program coordinator was seen to have been crucial to the program's success by providing personal contact and by getting all the families involved. Different families placed different values on the newsletters and pamphlets. One point brought up by the participants was the comparative lack of energy conservation in the work setting. They felt this may have detracted from their conservation efforts in the home.

1982 Study. A study in Roanoke, Virginia, (27) yielded the following results:

> In a large-scale field experiment, one showing of a 20-minute cable television program dramatizing simple conservation strategies resulted in significant savings on electricity, even in the absence of more intensive face-to-face contact [27:37].

The study used 150 detached, middle-class homes owned by the occupants. The utilities in these homes varied from all electric to electric with natural gas space and water heating.

Electric meters were read on all houses during a 3 week baseline period (24 June to 12 July). The houses were then randomly divided into five equal groups "to separate the effects of the program from those of the measurement system and from potential enhancement effects stemming from personal contact and social support" (27:41). The five groups were:

1. No-contact control group. This group had no involvement with the information programs.

2. Contact control group. This group completed weekly clothing and comfort forms and pre- and post-information surveys.

3. No-contact media group. This group watched a 20-minute energy conservation television program and received a 10-page booklet depicting conservation strategies shown in the program.

4. Contact media group. This group was the same as the no-contact media group, except that participants completed the same forms as members of the contact control group.

5. Contact media-home visit group. This group was the same as the contact media group. Additionally, this group received a 30-minute visit from one of the program directors. This visit was to explain the procedures mentioned in the program, help the residents develop conservation strategies, and obtain verbal commitment to try the strategies.

The 20-minute television program "Summer Breeze" was shown on four different days in mid-July. The members of the last three groups watched at least one of these showings. The other two groups (control groups) did not see the program.

The program started with several short, diverse scenes giving reasons for conserving energy. This was followed by a dramatized story showing a couple's dismay when they compared their high energy bill with their neighbor's lower energy bill. The settings and participants in the program were similar to those of the group members. The neighbors then began to demonstrate their different conservation strategies, dispel false beliefs, and emphasize key points. Voiceovers and captions emphasized and reviewed key points. These points emphasized personal benefits and stressed how this could be accomplished without loss of comfort. The households watching the program also received a ten page booklet depicting the strategies shown in the program. The study noted the program and booklet should be considered together when interpreting the results. However, prior research had consistently found information booklets alone to be ineffective.

A revised television program was shown to the same groups the following winter. This program was about winter energy conservation. A similar booklet based on this revised program was provided.

This study's results (see Table IV) showed an average electricity consumption increase of about 7.2 percent for the two non-media control groups (groups 1 and 2). This was for the 3 week period (warmer weather) following the 3 week baseline period. The three media groups (groups 3,4, and 5) averaged a 2.9 percent reduction during the same 3 week follow-up period (27:45). The 3 week winter period also showed the media groups consumed less energy than the non-media groups.

The study examined the specifics of each of the five groups. There is a possible problem with trying to infer differences between the "no-contact", "contact", and "visit" segments of the study. If the five groups are assumed to be relatively equal, then the differences in the baseline consumptions could be due to excessive electricity use in some of the groups. Under this assumption, the conserving group(s) consuming the most baseline electricity would have the most waste thus, these group(s) would yield the greatest savings. Also, the non-conserving group(s) using the most baseline electricity would have the most waste of these groups. Thus, these group(s) would probably tend to waste a

TABLE IV

Television's Impact on Energy Conservation

Mean Kilowatt-Hour Electricity Consumption

	Group Number 1	2	3	4	5
Baseline Consumption Avg (kilowatt-hours)	44.2	40.2	48.2	38.7	40.9
Summer Consumption Avg (kilowatt-hours)	48.0	42.5	46.5	37.9	39.7
Change (%)	+8.6	+5.7	-3.5	-2.1	-3.0
Winter Consumption Avg (kilowatt-hours)	33.6	31.4	30.5	28.0	29.3
Change (%)	-24.0	-21.9	-36.8	-27.7	-28.4

Group 1 No-contact control group

Group 2 Contact control group

Group 3 No-contact media group

Group 4 Contact media group

Group 5 Contact media-home visit group

higher percentage of electricity as the demand increases or conserve a higher percentage as the demand decreases. Both of these situations occur in this study.

Probably, the only realistic separation that can be made is between the media and non-media groups. This is where the most significant difference in electricity consumption occurs. This would negate any conclusions about the effects of any additional contacts made on the residents. However, this would not affect these overall findings:

> The results of this study indicate that, with minimal interpersonal support, one brief but highly specific and targeted program promoted overall home energy savings of about nine to ten percent [27:48].

The residents generally adopted simple and no-cost strategies discussed in the program instead of the more involved and cost intensive programs. Therefore, the savings should be based on these programs.

At the time of the study (1982), the economic and political environment was not conducive to energy conservation. Energy supplies were more abundant and costs were relatively low compared to other times since 1973. Greater savings might have been achieved under more extreme conditions as seen in more severe energy crises (27:48).

A second television program using the same actors but a different format was used. This program was presented in a "talking head" format with no demonstrations of techniques or descriptions of procedures for conserving energy. The residents viewing this program did not change their behavior (27:39).

<u>Voluntary Conservation Manual</u>. (20) "Energy Management for Navy Family Housing: A Manual for Voluntary Residential Energy Conservation" lists ten principles used in a conservation program. These principles primarily involve education. Five of these were discussed in the previous two studies. These include: using personal communication, providing information, involving the entire family, developing and maintaining pro-conservation attitudes, and providing usage feedback.

This manual lists five additional principles not yet discussed. First, vary program intensity. The intensity should be greatest during the high consumption periods. As the seasonal consumption lessens, the program intensity should also lessen. This will prevent the occupants from feeling inundated and "tuning out" the program.

Second, set challenging, but attainable conservation goals. As mentioned in the previous section, studies have shown that conservation goals lead to decreased energy consumption.

Third, express concern about conservation. This concern must be sincere. The participants in the Navy's 1979 study commented on the lack of conservation efforts in their workplaces. They felt this lack of concern in the workplace had a negative effect on their conservation efforts at home. An energy conservation program must encompass the whole base, not just MFH, to increase its effectiveness.

Fourth, demonstrate support. The housing office needs to demonstrate its concern for energy conservation. Also, Civil Engineering needs to readily respond to MFH energy related maintenance and repair items.

Finally, commend conservation efforts. Recognize individual occupants for reducing energy consumption. Recognition could be in the form of prizes, commendations, or verbal praise.

Occupant Energy Payment. (23) Another type of energy conservation program is to have residents pay for the energy they consume. This program is based on the cost based model relating energy consumption with cost to the resident. Presently, utilities are provided with the quarters in exchange for the occupants' BAQ (basic allowance for quarters). Essentially, utilities are included in the rent and are not directly paid for by the occupant.

In 1977, Congress enacted Public Law 95-82 which directed the Secretary of Defense to accomplish the installation of energy meters on all MFH units, to establish a consumption ceiling, and to assess charges to the occupants of energy consumption in excess of the ceiling. The feasibility of this program was to be investigated before its implementation.

The study by the Office of the Deputy Assistant Secretary of Defense (23) investigating the feasibility of this law can be broken into different parts. These parts consist of meter installation, Norm development (to establish a consumption ceiling), program operations, and alternatives or possible variations of the original program. The adverse impact to the occupants and the overall costs versus savings were also examined (see Table V). All costs given are in 1981 dollars.

Meter Installation. The Department of Defense had looked into the feasibility of installing meters on MFH prior to the enactment of Public Law 95-82. Various problems were encountered in this study. The main problem involved the existing utility layouts. Many MFH units are multifamily structures. The structures were built without having to meet any requirement for individual metering. Therefore, the existing electric, gas, steam, chilled and heated water, and domestic hot water lines are not conducive to individual meters. Changing these lines to allow for individual meters could involve very extensive work. The livability of these houses could be impacted in more extreme situations requiring a vacancy of up to 6 weeks. The costs of installing meters per unit could range from $129 for straight forward units to $5,536 for more extensive work. Extreme situations could exceed $35,000 per unit. The total number of meters to be installed would be approximately 300,000 to cover DOD housing in the 50 states and the U.S. possessions. The total cost would be approximately $415,000,000 (23:ES-1,ES-3).

TABLE V

Occupant Energy Payment

Costs Versus Savings For Occupant Payment (in thousands of 1981 dollars)

	Billed for Excess		Full Payment
	No Reward	Reward	
	Initial Program	Alt 1	Alt 2
Initial Costs			
Meter Installation	$415,000	$415,000	$415,000
Norm Development	50,199	50,199	NA
Total Initial Cost Amortized Over 25 Years	18,608	18,608	17,614
Annual Costs			
Program Operation	55,579	56,697	57,777
Total Costs	74,187	75,305	75,391
Annual Savings			
Percent	6%	12%	12%
Value	31,867	63,734	63,734
Overall Net Loss	42,320	11,571	11,657
Personnel Losses From Adverse Impact (Not Included Above)			
Percent	1/4%	1/8%	1/2%
Cost	118,000	59,000	36,000

Norm Development. A computer program was developed to identify a Norm for each household. This Norm should predict the energy required (a consumption ceiling) in each house. The Norm is derived from over 300 variables per month. These variables include items such as house size and construction, family size, and climatic conditions. This study revealed the reliability of the Norm would probably not exceed 85 percent. This results in a significant possibility that the consumption ceiling estimated for a particular unit could be quite unfair. Another problem with the Norm is that it only affects occupants consuming energy in excess of the Norm. There is no conservation incentive for the occupants consuming less than the Norm. Some of these occupants may see their conservation efforts as too intense if they are consuming less than what is considered to be a fair amount (Norm). This may lead to an increase in energy consumption for some of these occupants. The estimated cost for Norm development and the required minicomputers and software to apply the Norm is $50,199,000 (23:ES-4).

Program Operation. The ongoing operation of the program would consist of several items. Additional personnel would be required to read the meters, adjust Norms, send out bills, and collect occupant payments. Recurring meter maintenance would also be required. Housing repair and maintenance costs would increase as occupants make more work requests to help decrease their energy consumption. The total annual operating cost is estimated at $55,579,000 (23:ES-10).

Adverse Impact. The study also looked at the adverse impact on personnel. After a comprehensive review, it was determined that negative retention could result from perceived changes in the employment contract. An estimated one-fourth of one percent of career military personnel are expected to be affected. The expected cost is $118,000,000 for the replacement of these personnel (23:ES-5).

Costs Versus Savings. (23:ES-10) The total initial cost is about $465,199,000 for the meter installation, Norm development, minicomputers, and software. The annual operating cost is about $55,579,000. The estimated energy savings is 6 percent. Energy costs were assumed to increase at a 10 percent annual rate from a 1978 baseline. Assuming energy consumption remains the same without the program, the annual cost savings would be about $31,867,000. Subtracting out the annual operating cost and initial cost (amortized over 25 years) results in an annual net loss of $42,320,000. This does not include the $118,000,000 loss from personnel replacement costs which may be spread over several years.

Alternative 1. (23:ES-10) By adding a reward system to the original program for occupants consuming less energy than the Norm, the energy savings were expected to double to 12 percent. Additional costs would consist of additional accounting requirements for sending out rewards and the rewards themselves. The personnel losses are expected to be half of the losses in the original program. The overall program is expected to result in a net loss of $11,571,000 per year.

The estimated 12 percent energy savings may be a little optimistic. The reward system may prevent the possibility of occupants increasing their energy consumption to meet the Norm. However, the incentive to gain from a reward will not be that great. As discussed in the previous chapter, the fear of loss is a greater incentive than the possibility of gain. Also, the occupants' comfort level is at their present energy consumption level. Under the comfort based model discussed in the previous section, most occupants will maintain their comfort level without regard to any non-major outside stimuli.

<u>Alternative 2</u>. (23:ES-7,ES-10) The second alternative was based on installing meters on MFH and having the occupants pay directly for the energy consumed. An energy allowance would have to be given to these occupants to prevent breaching an implied contract of employment. This program would not require the usage of a Norm. Therefore, the initial cost would be less than the two previous programs. The annual operating cost would be a little higher due to increased MFH maintenance and repair requests. This alternative is expected to yield a 12 percent energy savings. The overall program is expected to result in an annual net loss of $11,657,000.

The estimated 12 percent energy savings may be a little optimistic. This alternative's savings is based on the strength of association of the cost based model with the occupants' consumption. As discussed in the previous section, studies tend to show costs primarily affect lower income households while higher income households will probably not decrease their consumption if their comfort level is decreased.

Maintenance, Repair, & Construction. The two previous sections discussed energy savings attainable through the occupants' actions. This section examines potential energy savings that may be attained through measures applied to the housing units. Two separate studies (DOD study and Navy study) are examined. The various measures are compared as to their effectiveness and cost. The effects of equipment efficiency are also examined.

The expected savings from this type of energy conservation program can sometimes be overestimated by not allowing for possible increased energy consumption. For example, "once efficiency of insulation is improved, people may use their appliances or space conditioning more. This can partially or completely offset the potential cost savings" (8:23). This increased consumption could be seen as a benefit as stated in the following:

> Economic theory suggests that some of the benefits of technical efficiency improvements will be taken in reduced operating costs (as measured by energy savings) and some will be taken as increased comfort (e.g., higher space heating temperature settings after retrofit) [15:424].

If the reason for this increased consumption is based on the cost model, then MFH energy consumption would probably not increase significantly after facility improvements.

DOD Study. (23:8.11-8.17) The feasibility study discussed in the previous section for metering all MFH included the investigation of another alternative. This alternative consisted of two parts: altering the characteristics of all DOD family housing and developing a new source of energy.

The housing retrofit concentrated on reducing the space heating and cooling requirement which accounts for 60 percent of energy demand in a typical home. This reduction was accomplished by installing insulation throughout the house, adding thermal blanketing on the windows, and caulking and weather-stripping to decrease infiltration.

The new source of energy provided was solar heating for domestic hot water. This program is only feasible for certain locations.

The following estimated costs are in 1981 dollars. The cost of building improvements is $297,000,000 with an annual maintenance cost of $10,327,000. The cost of solar conversion is $100,000,000 with an annual maintenance cost of $2,000,000. After amortizing the initial costs over 25 years, these programs result in a net savings of 12 percent (11 percent for facility improvement and 1 percent for solar energy). Based on 1978 energy consumption levels and assuming that energy costs increase at 10 percent per year, the net annual dollar savings (in 1987 dollars) is $35,527,000.

<u>Navy Study</u>. (22:6.56-6.72) Like the previous study, this study also examined energy consumption reductions resulting from house modifications. MFH units were used at Port Hueneme, California; Fort Hood, Texas; and Great Lakes Naval Training Center, Illinois. At each of these locations, two similar houses were compared using the Norms discussed in Chapter 3. One of the houses underwent various energy conservation modifications involving exterior doors, windows, and walls; ceiling and roof; floor; and infiltration. The other house was the control and had no modifications accomplished. At each of the locations, a comparison of energy reduction was performed (see Table VI). This was accomplished by adding the modifications one at a time. After each modification, the energy consumption was compared between the Norms of the test and control house. Some of the improvements corresponded with an increase in energy consumption. This was mainly prevalent in the warmer period requiring cooling. The study noted this increase was due to air temperatures being lower outside the house. The new conservation modifications hindered the dispersal of the warmer air from the house. This reinforces the effectiveness of the modifications but stresses the need for the occupants to open windows on cooler days during the cooling period to conserve energy. There was no cooling conservation for Port Hueneme.

TABLE VI

Conservation Per Modification

	Energy Conserved Per Modification Per Season				
	Great Lakes Naval Center		Fort Hood		Port Hueneme
Modification	Heat	Cool	Heat	Cool	Heat
Windows	12%	(4.2%)	14.6%	.1%	41%
Walls	8.4	.7	22.4	6.2	53.5
Roof	(.14)	1.3	21.9	17.1	(.8)
Floor	4.7	(4.1)	1.7	(.7)	5
Infiltration Reduction	25.4	(5.7)	9.4	3.1	13.7
Combined	47.1	(14.6)	67.2	25.8	96.9

The following conclusions were based on the results of the study:

1. Replacing single glass windows with double glass windows resulted in significant reduction of heating loads.

2. Improving thermal characteristics of floors and attic roofs contributed little to no reduction of heating loads.

3. Infiltration reduction had a large effect on reducing energy consumption and was a large part of total energy savings.

4. Addition of R-11 or R-19 blanket insulation to exterior walls significantly reduced the energy loads but replacing R-11 with R-19 resulted in little reduction in energy loads.

Equipment Efficiency. Using more efficient equipment in a house has a significant impact on energy consumption. This pertains to household appliances as well as the major equipment items such as air conditioners and water heaters. The cost of more efficient equipment may be greater than other equipment; however, the energy savings may well offset this cost difference. Several other factors affecting the equipment's life-cycle cost are equipment capacity, expected life of the equipment, and energy cost (12:11).

Personal appliances are the responsibility of the occupant. However, in MFH, major appliances and equipment such as heating and cooling systems, water heaters, ranges, and refrigerators are installed by the government. Heating and cooling equipment and water heaters account for as much as 70 percent of a house's energy consumption (12:1). Relatively little attention has been given to this area. Installing more efficient equipment could significantly decrease energy consumption.

Summary. This section examined various existing energy conservation programs. The programs can be categorized into one of the following three groups: occupant education; occupant energy payment; or maintenance, repair, and construction.

Before residents can conserve energy, they must know how. The programs discussed in this section are aimed at educating the residents in ways of conserving energy. The programs also provide information about the energy situation to help change attitudes about energy use.

The Navy's 1979 study resulted in a significant decrease in energy consumption. The program was relatively simple and inexpensive. The key to its success was a program coordinator to provide personal interaction with the MFH occupants.

The 1982 study involving a television program was also successful. The results of this program cannot be compared against the previous program. This is due to the problem discussed in Chapter 3 about comparing non-equal houses. The television program took the place of the personal contact. This was only possible because the program did more than recite information that could have been stated in a pamphlet. The message was presented in a format that was clear, specific, vivid, and in familiar terms. This program would be simpler and less expensive than the previous study. With the number of VCRs available, tapes could be widely disseminated. Copies could be made available for viewing in the housing office. Also, the Armed Forces Network could be used at overseas locations.

The Navy has found the following through its many studies:

> It is apparent that an energy conservation program would best be of an educational nature, emphasizing development of proconservation attitudes and providing information regarding energy-efficient practices, utility consumption, and costs [21:17].

The second group of programs has the MFH occupants being financially responsible for their utilities to reduce energy consumption. This includes assessing monetary penalties for energy consumption in excess of a set baseline, providing monetary rewards for energy consumption under a set baseline, and giving the MFH occupants an energy allowance and having them pay directly for their own utilities.

The cost of these programs includes initial costs such as meter installations and operating costs such as a billing system. The adverse impact of these programs is also expected to result in some negative retention. Subtracting the total program costs from the expected energy savings results in a net loss for all three programs.

As energy costs rise, the break even point will be approached. If energy costs increase high enough, then a net savings will result. However, increasing energy costs would probably result in increased conservation efforts. This would decrease the potential percentage of energy savings from these programs.

The final group of programs involves the maintenance, repair, and construction of the housing units. These programs, while being relatively inexpensive, result in substantial energy savings. Thus, a net savings is achieved. There are no adverse impacts resulting from these programs. In fact, the occupants' comfort level should increase.

Future Energy Trends

Knowing about energy in the future is essential for making policies and implementing programs involving tomorrow's energy use. However, there are too many variables involved to know exactly what the future will bring. Some of these variables can be totally unpredictable such as nuclear power plant accidents or conflicts disrupting the flow of oil. Knowledge of existing predictions of future energy trends will enable better decisions to be made.

As discussed in Chapter 1, energy resurfaced as a serious concern in 1973. Energy has remained a concern since the 1973 energy crisis. There have been varying degrees of energy crises since 1973. Alternative and renewable energy sources continue to be pursued. This pursuit lessens as energy crises diminish. Because of this, "today's falling prices post more of a long-range threat to America than yesterday's rising prices" (13:445). Energy conservation behavior also decreases during the cycles of less severe energy crises. This is evidenced by the partial return of the 65 mph speed limit.

The main energy resources are nonrenewable and will eventually be depleted. There are two parts to this problem. First, the U.S. will probably deplete certain types of its resources before the remainder of the world's resources are depleted. If no alternative resources have been found by this time, then the U.S. economy and national security will be dependent on the countries having these resources. Eventually, these resources will be depleted. This will leave alternative and renewable energy which has yet to adequately developed as the only energy source. The time available until nonrenewable resources are depleted is dependent on three factors: the quantity of the resource, its rate of consumption, and how soon until alternative energy sources are available. The nonrenewable resources may last years, decades, or even centuries depending on the resource. The important point is it may take 50 years for one form of energy to supersede another (24:68).

This section examines the future usefulness of several energy sources. These energy sources include oil, natural gas, coal, nuclear power, and various renewable resources. Also, energy trends pertaining specifically to residencies are examined.

Oil. There are three main reasons why oil's importance is emphasized in today's energy arena. First, oil is the primary energy source in the U.S. Approximately 50 to 55 percent of the country's energy is derived from oil (9:554). Oil is also an important part of producing many products such as fertilizer, plastics, medicines, and clothing.

The second reason for emphasizing oil is the dependency on foreign countries for this resource. "The U.S. still relies on unstable foreign sources for 28 percent of its oil" (3:10). This percentage should increase as U.S supplies decrease. The U.S. has less than 5 percent of the world's known oil reserves. Some people believe additional reserves will be found in the U.S. (13:448). Others believe the "prospects are quite gloomy about finding any major, large oil fields in the future" (9:554). If new reserves are not found, the U.S. will be consuming its last 10 percent of oil in 15 years. The energy required to retrieve any remaining oil will be greater than the amount of energy in the oil itself (9:554-555). This will result in a greater dependency on foreign countries and higher oil prices.

Finally, even if the U.S. is able to maintain stable foreign oil markets and absorb the higher oil cost, the world's oil supply will eventually be depleted. Based on current consumption rates, there is an estimated 75 years supply of recoverable oil (14:76). Even though the efficiency of oil's use should increase, the rising world population with its incresing demand for oil will offset these savings.

Natural Gas. Natural gas is in a similar situation to oil. Its uses are not as varied; therefore, its potential impact is less severe. Estimates show only a 60 year supply of recoverable natural gas (14:76).

Coal. There is a more abundant coal supply in the world estimated to last 350 years. There is enough coal in the U.S. alone to power this country well into the twenty-third century. Coal accounts for over 80 percent of the recoverable fossil fuel resources in the U.S. while oil accounts for only 4 percent (14:74-76).

Coal's main disadvantage is its association with pollution and acid rain. This association is much less now than it was in the past. Today's technology uses sound waves, microwaves, and electron beams to remove impurities allowing for much cleaner burning. Continued improvements with lasers and genetic engineering are being pursued to virtually eliminate any adverse environmental impact. Modern coal-fired power plants are cleaner than most older oil-fired plants. Sulfur emissions, a suspected cause of acid rain, have declined 20 percent in the last 20 years while coal's use has increased over 85 percent (14:74-75).

<u>Nuclear Power</u>. One of the most controversial forms of energy is nuclear power (fission) because a potential accident could be disastrous even though the probability is very small. Nuclear power is safe but not 100 percent safe. Incidents such as Chernobyl, Three Mile Island, and various smaller incidents have influenced public opinion. This has probably slowed the development of nuclear power more in the U.S. than most other countries. The U.S. derives about 14 to 15 percent of its electricity from nuclear power and is expected to increase to 20 percent in the 1990s. France derives 60 percent, a figure expected to rise to 73 percent by 1995 (14:75). For various reasons, the U.S. is not able to build nuclear power plants as fast or inexpensively as other countries resulting in nuclear

energy costing 67 percent more in the U.S. than in many other countries (9:555).

Nuclear power is not an inexhaustible energy source as believed by some people. "The free world has over 91 years' supply of uranium ore at 1984 production levels to operate reactors in the free world" (14:76). The U.S. has more uranium reserves than any other country.

Renewable Energy. Within 30 years, the supply potential for renewable energy could exceed present total energy consumption (14:76). This is dependent on how actively these sources are pursued. Some of the various renewable energy sources being used or investigated are hydro, solar, wind, geothermal, biomass, and nuclear fusion.

Hydropower is the result of using dams to channel water to turn electricity generating turbines. About 14 percent of U.S. electricity is produced this way. There will probably be little increase in the amount of hydropower being produced. Most of the good dam sites have been developed, and there are ecological concerns over the construction of new dams (25:14; 6:4).

Solar power can be divided into two different types. First, solar radiation can be collected to heat water for domestic hot water or space heating. The water could be heated enough to produce steam to turn electricity generating turbines. The second type of solar power is the conversion of sunlight directly into electricity with solar cells. The cost of this technology has dropped to $10 per watt from $600 per watt in 1959. Solar cells will be considered cost effective when the cost drops to around $3 per watt (6:4). Since solar cells operate only in the sun, a storage system for nighttime use would increase the effectiveness of this energy supply. However, without a storage system, solar power would still decrease nonrenewable energy resources during the day when energy consumption is highest.

Wind power, though not a new concept, has only recently begun to be harvested using modern technology. The new designs and materials enable large, efficient wind turbines to be constructed capable of withstanding strong gales. An array of over 100 wind turbines is required to equal the electrical output of modern fossil fuel, nuclear, or hydroelectric power plants (6:5). These "wind farms" may have aesthetic drawbacks and sometimes interfere with radio and television signals. Presently there is little electricity produced with wind power. However, a study completed by General Electric in 1977 reports favorable locations to produce at least 13.6 percent of the national electricity demand (17:73). This conservative estimate does not even include the many potential off shore sites. The locations considered were in unpopulated areas near existing power grids. In 1984, the California Energy Commission estimated windpower costs would be competitive with hydroelectric power and cheaper than all other energy forms by 1990 (17:73).

Geothermal energy is the use of underground hot water or steam to either heat facilities directly or turn electricity generating turbines. Geothermal power plants already in use are capable of meeting the electrical demands of large cities. Sitings of these plants are limited to volcanic hot-spot areas, thus, the contribution to the U.S. energy supply is likely to be small (6:6).

Biomass consists of plant life suitable for use as a fuel. "Many energy-rich plants can be grown in the sea or on land that is not suitable for food crops" (6:5). This prevents competition with food production. Plant waste such as sugar cane stalks and corn cobs as well as garbage in general is usable. This contributes to solving another problem of waste disposal. Biomass energy use is expected to increase over the next few decades and is considered by many experts to always be a secondary source of energy in the U.S. (6:5).

Nuclear fusion, the fusion of atoms to form heavier atoms, produces the energy in the sun and other stars. "If scientists could start, sustain, and control nuclear fusion on Earth, humankind would have an unlimited source of clean energy" (6:6). For over 20 years, scientists around the world have worked on fusion. The consensus is this form of power will not be available for 100 years if at all (6:6).

<u>Residential Energy</u>. Residencies consume approximately 20 percent of the total U.S. energy consumption. A study by the General Accounting Office (GAO) predicts a 40 percent

residency increase between 1973 and the year 2000. However, the net residential energy consumption (total energy consumed in the residencies) is expected to increase only 9 percent (11:24,26). This is due to increasing residential energy efficiency.

Appliance efficiencies have also and will continue to increase. The National Appliance Energy Conservation Act of 1987 requires new appliances' efficiencies to increase 15 to 25 percent over their 1985 levels within the next one to three years (1:1-G). This should help offset the increasing number of appliances requiring energy.

Electricity accounted for 21.6 percent of the net residential energy consumption in 1977. The percentage is expected to rise to 31 percent in 1990 and 35 percent by the year 2000. Electricity involves substantial conversion, transmission, and distribution losses. Gross energy is the total energy at the original source before any conversion, transmission, and distribution losses are accounted for. Therefore, gross energy consumption increases faster than the net energy consumption as the percentage of electricity use increases. Gross residential energy is expected to increase 32 percent between 1977 and the year 2000 (11:29). Recent breakthroughs in superconductivity show promise for decreasing electrical transmission loss. This could eventually lead to "superconducting cables that could transmit electricity from a power plant to a distant city with essentially no energy loss" (16:62). This would result in a dramatic increase in electricity's efficiency reducing gross energy consumption.

Coal and nuclear power produce most (68 percent) of the U.S. electricity. This is expected to increase to 74 percent by the 1990s (25:8). Increased conversions to electricity relates to less use of oil and natural gas which are less abundant. Natural gas is still the most used heating source. However, electricity has overtaken fuel oil as the second most used source (26:11).

Summary. The U.S. is the largest energy consumer in the world. While possessing only 6 percent of the world's population, this nation consumes 30 percent of the world's energy (9:554). The U.S. energy demand is conservatively estimated to increase 20 to 25 percent by the year 2000 (17:16).

Residential energy (20 percent of the total consumption) is expected to increase only slightly while the number of residencies increases significantly. The percentage of electricity usage in these residencies should also increase. This will place a greater dependence on coal and nuclear power which procures most electricity in the U.S. Hydroelectric power, a renewable energy source, also produces some electricity. This greater electricity dependence will decrease residential dependence on oil and natural gas which are in shorter national and international supply than coal or nuclear power. Therefore, cost increases and energy disruptions should not be as great.

Alternative and renewable energy sources being pursued such as biomass, geothermal, wind, and solar power are all used for electricity production. If these sources are adequately developed, electricity supplies should be maintained and cost kept down if not cut back.

Electricity is not a very efficient energy source because of the energy losses during conversion, transmission, and distribution. Recent breakthroughs in superconductivity may lead to a decrease in these losses resulting in increased efficiency.

Natural gas is still the most used energy for heating residencies. Electricity has recently overtaken fuel oil as the second most used source.

The various energy sources will probably remain fairly competitive over the next several years or even decades. Oil will continue, as it has in the past to cycle through shortages and surpluses. At some point in the future, oil and natural gas will be the first of the major energy sources to be depleted. Electricity will probably become almost the only means of supplying energy to residencies. Coal, hydroelectric, and nuclear power should be able to meet the demand for awhile. If nuclear fusion can be developed, then the energy problem will be solved. This could take 100 years if at all. The development of renewable energy will probably be needed to prevent intermediate long-term energy shortages with the associated cost increases.

V. Summary, Conclusions, and Recommendations

Summary

This research had two objectives. The first objective was to determine whether MFH energy consumption was comparable to energy consumption in non-MFH residencies. The second objective was to determine the feasibility of decreasing MFH energy consumption.

The general consensus is MFH occupants consume more energy than their non-MFH counterparts. The predominate reason given for the alleged higher consumption is based on the MFH occupants not paying directly for their utilities. MFH utilities are included with the quarters in exchange for the occupants' forfeiture of their BAQ (basic allowance for quarters). This perception of higher MFH energy consumption led to Congressional enactment of Public Law 95-82 which directed the Secretary of Defense to install energy meters on all MFH units, establish an energy consumption ceiling, and assess charges to the occupants for energy consumed in excess of the set energy consumption ceiling. The programs's feasibility was to be investigated prior to its implementation.

This research presented a background of previous energy shortages. This was to provide an understanding of some potential causes, problems, and results that may be beneficial in coping with present and future energy shortages.

Two past energy shortages include a European wood shortage in the sixteenth and seventeenth centuries and a whale oil shortage in the nineteenth century. In both situations, the demand outgrew the supply. Even though the costs rose, the demand did not decrease. The energy sources were almost permanently depleted by the time alternative sources were developed. The wood and whale oil were renewable energy sources and were able to replenish themselves. Today's energy crisis is the result of diminishing nonrenewable energy sources. So far, no alternative energy sources have been adequately developed. These nonrenewable resources will not be able to replenish themselves if or when alternatives are developed.

To resolve the first objective, this research analyzed several existing studies. These studies compared energy consumption in residencies having utilities included in the rent with energy consumption in residencies where the occupants payed directly for the energy consumed. Some of the comparisons were between MFH and non-MFH residencies. Other comparisons were between two non-MFH groups. The studies examined were conducted in different locations and time periods and used varying methodologies. One particular study was examined in detail. This study used a set of norms to control most pertinent variables such as house construction and number of occupants.

To resolve the second objective, this research examined individual behavior, previously incorporated energy conservation programs, and future energy trends. The behavioral approach was accomplished by a literature review to derive a relationship between energy behavior and energy attitudes, energy costs, social norms, and other factors. Existing energy conservation programs were examined to compare the various programs' effectiveness. Future energy trends were examined to understand the future energy environment that today's and subsequent policies must be based on.

Conclusions

First Objective. The first objective was to determine whether MFH energy consumption was comparable to energy consumption in non-MFH residencies. The studies examined had varying results ranging from no difference to 35 percent greater energy consumption in MFH. The studies showing the greatest differences tended to control the least number of variables. These studies did not take into account such factors as house construction, house size, number of occupants, etc. which prevents a comparison of the two housing groups under near equal conditions.

Studies between two groups of non-MFH residencies also showed higher energy consumption by occupants having utilities included in their rent. This energy consumption difference was usually larger than differences between MFH and non-MFH residencies without utilities included in their rent. Some of the possible reasons MFH reflect less energy consumption differences are possible use of lockable thermostats with minimum and maximum settings, "no heat" and "no cool" seasons, education programs, and realization by MFH occupants that the utilities are a benefit that may be taken away if abused. Therefore, studies comparing energy consumption between two groups of non-MFH residencies should not be used to analyze energy consumption in MFH.

A study at Port Hueneme, California, controlled most pertinent variables to enable a near equal comparison of MFH and non-MFH energy consumption. These variables include climatic conditions, house size, family size, appliance energy consumption, and the house itself. The housing variables include exterior surface U-values, surface absorbability,and shading coefficients; building air changes per hour; attic air changes per hour; air leakages through ducts; ground reflectance; and effects of thermal lag on facilities. Without controlling these variables, MFH energy consumption was 30 percent higher which was similar to other studies not controlling variables. Controlling the variables resulted in 13 percent less energy consumption in MFH under near equal conditions. This emphasizes the importance of controlling the different variables to attain near equal comparisons. These results may have been more favorable toward MFH than possible results in other locations due to mild weather conditions. In more extreme weather conditions requiring more heating and cooling, the non-MFH residents may have conserved more energy to offset increased energy consumption and costs. However, when factors beyond the occupants' control were eliminated, the MFH occupants actually consumed less energy than non-MFH occupants.

The examined studies took place at various times. As energy cost rose since the 1973 energy crisis, these studies showed no increase in energy consumption differences between MFH and non-MFH residencies. Some studies showed MFH had a greater energy consumption decrease than non-MFH residencies during this time. This was probably due to greater MFH conservation efforts. Also, excessive consumption (more waste) in MFH prior to this period would have meant more potential savings from conservation efforts since 1973.

Overall, most of the existing studies reflect higher energy consumption in MFH than non-MFH. Based on the Port Hueneme study, most of this is probably due to factors beyond the occupants control. This would mean energy consumption by MFH occupants is comparable to non-MFH occupants under near equal conditions. This could be verified by similar studies (controlling all pertinent variables) at various locations.

Second Objective. The second objective was to determine the feasibility of decreasing MFH energy consumption. The first objective showed comparable MFH and non-MFH energy consumption under near equal conditions. Not controlling the pertinent variables making the near equal conditions (as in the Port Hueneme study) reflected higher

MFH energy consumption. Certain variables such as family size cannot be regulated. Existing houses cannot be decreased in size. Constructing new houses smaller than existing houses would yield little savings and would not be viable. The two most plausible options are to increase the MFH energy efficiency and to decrease the occupants' energy consumption.

Increasing the MFH energy efficiency involves two parts. The first part involves maintenance, repair, and construction of the housing unit. This pertains to using proper construction materials and techniques to reduce the houses' heat loss, heat gain, and number of air changes. A Department of Defense study (23:8.11-8.17) estimated an 11 percent cost savings after maintenance, repair, and construction costs. Some of the work accomplished on the houses include weather-stripping doors and windows to reduce infiltration, installing lockable thermostats with minimum and maximum settings, solar shading, and adding insulation to ducts and water heaters. The 11 percent savings is based on 1978 energy consumption levels. These savings could vary depending on the energy climate such as varying energy costs and availability or other factors affecting residents' conservation efforts. The second part of increasing MFH energy efficiency involves the use of efficient equipment (HVAC, water heaters, etc.) and appliances (refrigerators, stoves, etc.). The generated savings can quickly offset the higher initial costs.

The second plausible method for decreasing MFH energy consumption involves decreasing energy waste (excessive energy consumption by the occupants). Energy use is affected by energy education, cost to the occupant, and feedback

Energy education involves educating MFH occupants about the need for conserving energy and how to conserve energy. Many people believe there is no energy crisis or the U.S. is not dependent on other countries for energy. Others are unaware of the serious consequences that may result from energy shortages. Incorrect or lack of knowledge affects these people's attitudes.

Studies disagree as to whether attitudes affect energy conservation behavior. Attitudes probably affect some people, possibly everyone to some degree. People must be informed in order to develop the right attitudes. The residents must also know how to conserve energy to reap the benefits of their desire to conserve. The information provided must be perceived, accurately understood, favorably evaluated, and remembered. Therefore, the information must be clear, specific, concrete, vivid, in familiar terms [illegible] from a credible source. The media sources such [illegible] pamphlets, and flyers are more informative while [illegible] interpersonal face-to-face means are more [illegible]

In 1979, a Navy study (18) showed an [illegible] education program decreased MFH energy [illegible] least 4 percent, probably much more [illegible]

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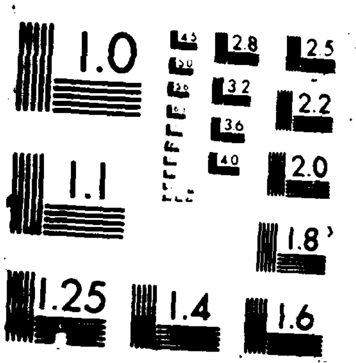
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showed an inexpensive 20 minute educational television program led to a 9 to 10 percent reduction in energy consumption. These two studies show inexpensive educational programs can attain significant energy savings.

Cost to the housing occupant is another factor affecting energy consumption. Most studies show lower income households' energy consumption is probably affected by energy cost, but there is less affect on higher income households. Therefore, having MFH occupants pay for their energy would probably result in lower income households decreasing their energy consumptions. The higher income households would probably maintain their present consumption levels in order to maintain their present comfort level.

A Department of Defense study (23) also stressed cost to the occupant with three programs to decrease MFH energy consumption by making the occupants financially responsible. These programs require metering of MFH to enable the occupants to pay directly for their utilities, pay a penalty for consumption in excess of a baseline, or pay a penalty as well as receive a reward for consumption less than the baseline. The study estimated MFH energy consumption would decrease 12 percent in the full payment and reward programs and decrease 6 percent in the penalty only program. These three programs had large initial and recurring costs such as meter installation, meter maintenance, a billing system, and establishing a fair baseline for each house in the penalty and penalty/reward programs. These cost resulted in a net loss for all three programs.

Feedback is the third major factor affecting energy consumption. Feedback should be incorporated with any energy conservation program to allow the residents to know the program's effectiveness. This feedback should be presented in understandable terms such as dollars and cents instead of kilowatt hours. Feedback is also effective by itself without any other energy conservation programs.

The outlook of energy in the future impacts the direction of today's policies and programs. Energy costs are expected to continue to rise. As this happens, the monetary savings produced by energy conservation programs will increase. However, the program costs should not increase. Depending on how high the energy costs rise, the energy conservation programs showing a net loss will approach the break-even point and may start to show a monetary net savings. The programs already producing a net savings will increase their monetary savings.

Electricity is and will continue to be a primary form of energy for housing occupants. Some occupants are also dependent on natural gas for such items as space heating, water heating, cooking, and clothes dryers. Natural gas may presently be as inexpensive or more inexpensive than electricity. The next few years or decades will probably see natural gas's price increase as its supply decreases. Electricity's cost should not increase as drastically, if at all, if alternate, renewable sources are developed and its efficiency increases.

Recommendations

Recommendations for Energy Conservation. Existing and new MFH should continue to incorporate energy conservation techniques to reduce energy consumption. These techniques include installation of weather-stripping, insulating the exterior housing surfaces, ducts, and water heaters, using lockable thermostats with minimum and maximum settings, and installing energy efficient equipment and appliances. New houses should be built with individual meters. This is quite inexpensive when the meters are installed during the construction. Eventually, as the older housing units are replaced, all MFH would have individual meters allowing for energy consumption feedback to the occupants. If future conditions change making some type of occupant energy payment a viable program, the meters would already be installed enabling the program to be implemented faster and more inexpensively.

Educational programs should be expanded. These programs are very inexpensive compared to the potential energy savings. An energy conservation video geared toward MFH occupants should be developed. The video could be viewed at the housing office, checked out by the occupants, and shown on the Armed Forces Network.

Presently, it is up to individual bases to decide on the use of lockable thermostats with minimum and maximum settings. These thermostats should be used in all MFH and should be set to reasonable, comfortable ranges which would not conflict with most of the occupants. Thus, these lockable thermostats would only affect the very few occupants who abuse the system.

Programs for having MFH occupants pay their utilities should not be used. The expense of metering all MFH and operating such programs is presently greater than the expected savings to be gained. This is mainly due to the cost of having to rework utilities in existing facilities because they were not built for individual metering. Thus, these programs would result in a net loss to the government.

Finally, attention should continuously be given to future energy trends. Types of energy (natural gas or electricity) available for equipment and appliances should be examined as MFH is renovated and constructed.

<u>Recommendations for Future Research</u>. More studies in various locations should be conducted with controlled variables (similar to the Port Hueneme study) to compare MFH energy consumption with energy consumption of non-MFH residencies under near equal conditions. This will enable a determination to be made whether MFH occupants, in general, consume an amount of energy comparable to non-MFH residents.

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This study had two objectives: to determine whether energy consumption was comparable between MFH and non-MFH residencies and to determine the feasibility of appreciably decreasing MFH energy consumption. These objectives were accomplished by examining existing research and literature.

The study found energy consumption tended to be greater in MFH. However, most of this difference is probably due to factors beyond the occupants' control such as house size, house construction, and equipment efficiency. Energy consumption in MFH and non-MFH residencies tended to be comparable under near equal conditions.

Decreasing MFH energy consumption involves increasing the housing units' efficiency and decreasing the occupants' energy consumption. Increasing MFH energy efficiency can be accomplished by using more efficient equipment and appliances and using proper construction materials and techniques to reduce heat loss, heat gain, and number of air changes. These efforts result in a net energy and monetary savings as well as increased occupant comfort.

Decreasing MFH occupants' energy consumption can be enhanced by providing energy education and feedback. These conservation programs produce significant energy savings for a low cost resulting in net energy and monetary savings.

Programs relying on making the occupants financially responsible for the energy consumed are expensive. The major expense is the cost of installing meters in existing houses to enable monthly readings. While these programs do produce some energy savings, present energy costs are low enough to result in a net monetary loss.

Maintenance, repair, and construction of existing and new MFH should be enhanced to increase MFH energy efficiency. Programs should concentrate on providing MFH occupants energy education and feedback. Programs requiring meters should not be pursued. However, meters should be installed on new MFH during construction (when it can be done inexpensively) for possible future use as energy costs rise.

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